

## HAPTIC ACTUATOR INCLUDING PULSE WIDTH MODULATED WAVEFORM BASED MOVEMENT AND RELATED METHODS

### TECHNICAL FIELD

[0001] The present disclosure relates to the field of electronics, and, more particularly, to the field of haptics.

### BACKGROUND

[0002] Haptic technology is becoming a more popular way of conveying information to a user. Haptic technology, which may simply be referred to as haptics, is a tactile feedback based technology that stimulates a user's sense of touch by imparting relative amounts of force to the user.

[0003] A haptic device or haptic actuator is an example of a device that provides the tactile feedback to the user. In particular, the haptic device or actuator may apply relative amounts of force to a user through actuation of a mass that is part of the haptic device. Through various forms of tactile feedback, for example, generated relatively long and short bursts of force or vibrations, information may be conveyed to the user.

### SUMMARY

[0004] A haptic actuator may include a housing, at least one coil carried by the housing, and a field member movable within the housing responsive to the at least one coil. The haptic actuator may also include at least one mechanical limit stop between the housing and the field member and circuitry capable of generating a pulse width modulated (PWM) waveform for the at least one coil to move the field member from an initial at-rest position and without contacting the at least one mechanical limit stop. Accordingly, the field member may move, for example, from an initial at-rest position to a steady state operation, without contacting the mechanical limit stop.

[0005] The PWM waveform may have a pulse width that decreases over time for a number of pulses. The PWM waveform may have a constant pulse width after the number of pulses, for example.

[0006] The PWM waveform may have a decreasing amplitude for a number of pulses. The PWM waveform may have a constant amplitude after the number of pulses, for example.

[0007] The PWM waveform may be a bipolar waveform, for example. The PWM waveform may have a constant repetition rate. The housing, at least one coil, and field member may define a resonant frequency, and the repetition rate may be at an integer multiple of the resonant frequency, for example.

[0008] The circuitry may include an intermediate waveform generator capable of generating a bipolar square wave and a low pass filter coupled to the intermediate waveform generator. The intermediate waveform generator may be capable of generating an intermediate waveform based upon an exponential function, for example.

[0009] An electronic device aspect is directed to an electronic device that may include a device housing and wireless communications circuitry carried by the device housing. The electronic device may also include a haptic actuator carried by the device housing. The haptic actuator may include an actuator housing, at least one coil carried by the actuator housing, and a field member movable within the actuator

housing responsive to the at least one coil. The haptic actuator may also include at least one mechanical limit stop between the actuator housing and the field member, and circuitry capable of generating a pulse width modulated (PWM) waveform for the at least one coil to move the field member from an initial at-rest position and without contacting the at least one mechanical limit stop. The electronic device may also include a controller coupled to the wireless communications circuitry and the haptic actuator, and capable of performing at least one wireless communication function and selectively operating the haptic actuator.

[0010] A method aspect is directed to a method of operating a haptic actuator that may include a housing, at least one coil carried by the housing, a field member movable within the housing responsive to the at least one coil, and at least one mechanical limit stop between the housing and the field member. The method may include using circuitry to generate a pulse width modulated (PWM) waveform for the at least one coil to move the field member from an initial at-rest position and without contacting the at least one mechanical limit stop.

### BRIEF DESCRIPTION OF THE DRAWINGS

[0011] FIG. 1 is a perspective view of an electronic device including a haptic actuator according to an embodiment of the present invention.

[0012] FIG. 2 is a schematic block diagram of the electronic device of FIG. 1.

[0013] FIG. 3 is a more detailed schematic diagram of the haptic actuator of FIG. 1.

[0014] FIG. 4 is a graph of waveforms generated by the circuitry of the haptic actuator of FIG. 3.

[0015] FIG. 5 is a graph illustrating momentum versus voltage for pure sinusoidal input waveform and a PWM waveform output by the circuitry of the haptic actuator of FIG. 3.

[0016] FIG. 6 is a schematic diagram of a haptic actuator according to another embodiment.

### DETAILED DESCRIPTION

[0017] The present invention will now be described more fully hereinafter with reference to the accompanying drawings, in which preferred embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Like numbers refer to like elements throughout and prime notation is used to describe like elements in different embodiments.

[0018] Referring initially to FIGS. 1 and 2, an electronic device 20 illustratively includes a device housing 21 and a controller 22 carried by the device housing. The electronic device 20 is illustratively a mobile wireless communications device, for example, a wearable wireless communications device, and includes a band 28 or strap for securing it to a user. The electronic device 20 may be another type of electronic device, for example, a cellular telephone, a tablet computer, a laptop computer, etc.

[0019] Wireless communications circuitry 25 (e.g. cellular, WLAN Bluetooth, etc.) is also carried within the device housing 21 and coupled to the controller 22. The wireless